

N89-29788

318

211256

AM 351973

**HIERARCHIAL PARALLEL COMPUTER
ARCHITECTURE DEFINED BY
COMPUTATIONAL MULTIDISCIPLINARY
MECHANICS***

**Joe Padovan
Doug Gute
Keith Johnson**

University of Akron

***Work supported by NASA Lewis and monitored by Chris Chamis**

GOAL

Develop Architecture for Parallel
Processor Enabling Optimal Handling of
Multidisciplinary Computation of
Fluid-Solid Simulations Employing
Finite Element and Difference Schemes

Paper Outline

1. Goals
2. Paper Overview
3. Philosophical Directions
4. Modeling Directions
5. Static Poly tree
6. Dynamic Poly tree
7. Example Problems
8. Interpolative Reduction
9. Impact on Solvers
10. Summary
11. Future Directions

Philosophical Thrusts

1. Reduce Load Per Processor
2. Reduce Number of Processors
3. Reduce I/O Between Processors
4. Provide for Most Natural Route of I/O Flow Between Processors
5. Enable Optimal Handling of Model Topology
6. Enable Optimal Handling of Automatic Mesh Refinement
7. Provide Logical Framework to Implement Generalized Saint Venants Type Model Reduction

Modelling Directions

1. Static Single Level Models (Traditional Simulation)

- Modelling Requirements
Defined Initially

- No Changes Occur During
Computation

- 2. Dynamic Multilevel Models
 - First Level of Model Refinement Established by User
 - Multilevels of Refinement Established Via Automatic Physical Criteria ie.
 - Cavitation
 - Plasticity (Inelasticity)
 - Shock Formation
 - Flow Separation
 - High Stress and Strain
 - Gradients
 - Etc.

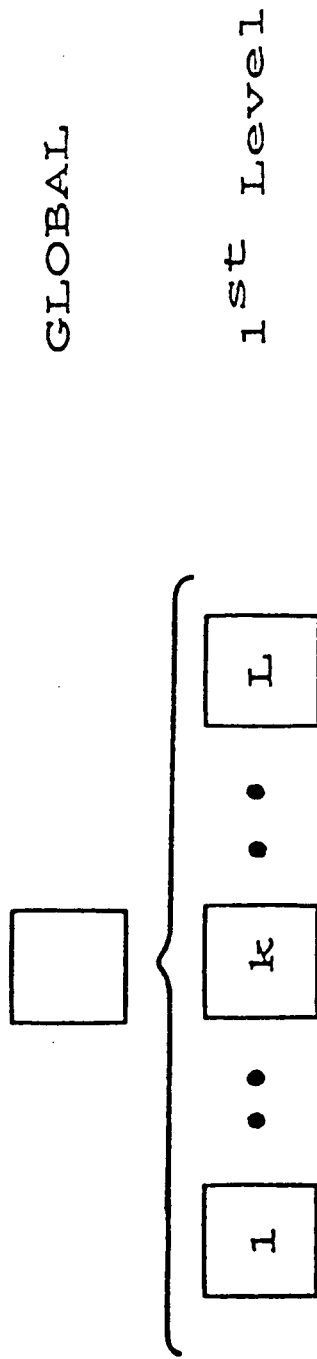
STATIC POLY TREE PARALLELISM

Steps

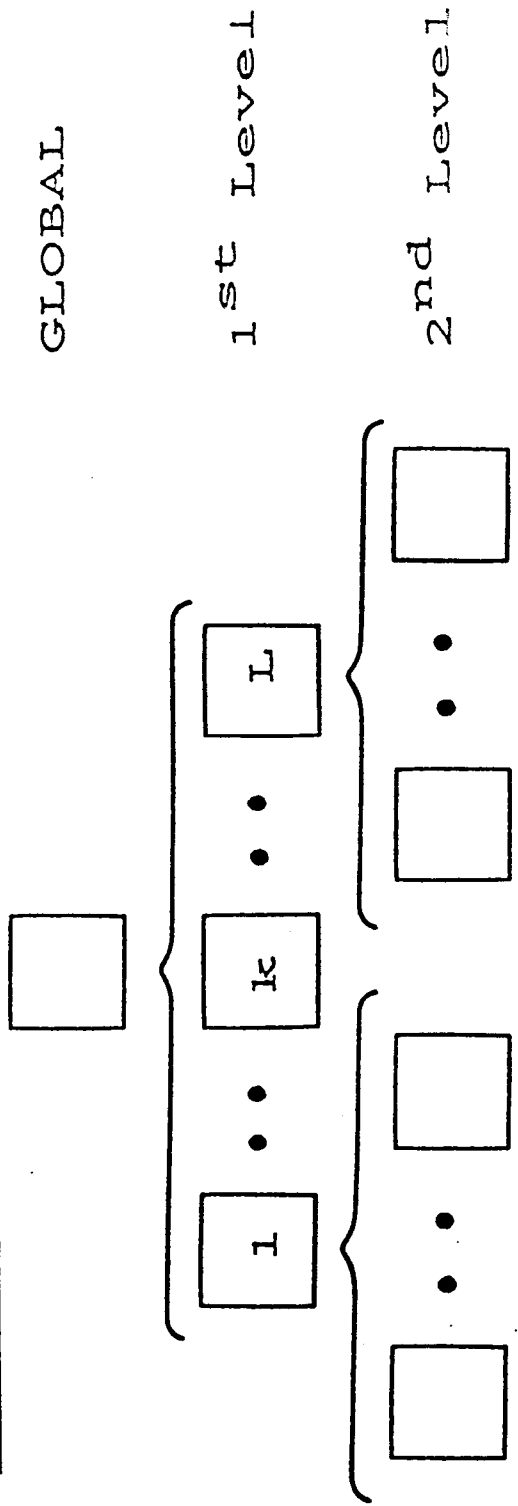
1. Static Model Organized into Convenient Substructural Components
2. Each Substructural Component is Partitioned into Optimal Number of 2nd Level Substructures
3. The Various 2nd Level Substructure May Themselves be Partitioned into a 3rd Level
4. The Process May be Repeated to Yield a Multilevel Poly Tree

DEVELOPMENT OF STATIC POLY TREE

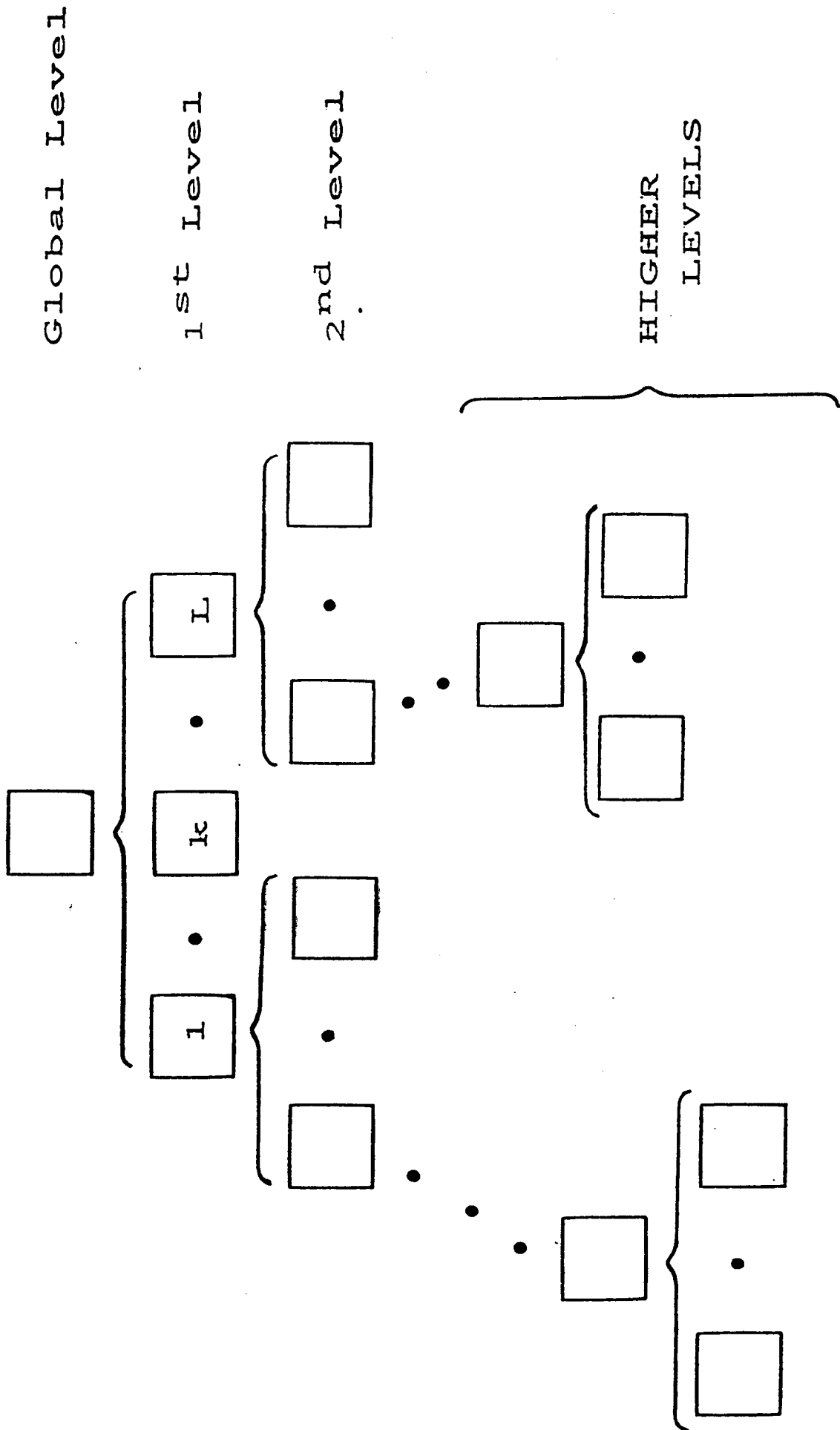
STEP 1



STEP 2



DEVELOPMENT OF STATIC POLY TREE



Choice of Levels and Associated

Partitions : Static Model

1. Number of Boundary and Internal Variables at Each Level/Partition Balanced to Yield
 - Optimal Hierarchy of Bandwidths
 - Minimum I/O Between Levels
2. Choice of Levels Contingent on
 - Reducing Load Per Processor
 - Minimize Number of Processors for a Given Level of Speed Enhancement

DYNAMIC POLY TREE PARALLELISM

Steps

1. First Level Organized into Convenient Substructural Components (Optimal in Static Sense)
2. Each Substructural Component Refined as Per Local Physics
3. To Maintain Optimality, Refinements May Require Several Levels of Processors

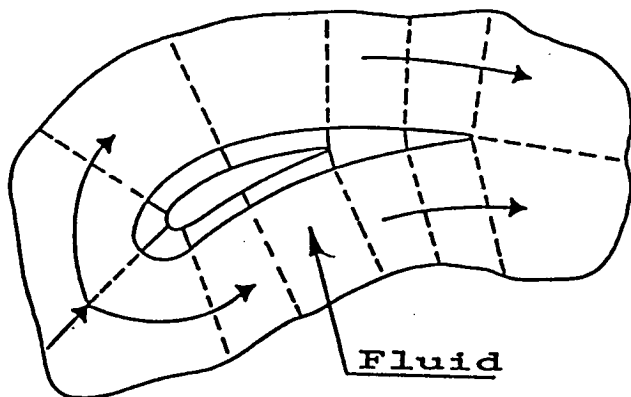
Choice of Numbers of Level &

Associated: Dynamic Model

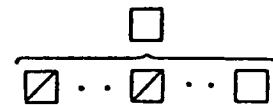
1. First Level Defined as Per Static Tree
2. Choice of Additional Levels and Associated Partitions Contingent on
 - Maintaining Optimality of a Given Branch of Poly Tree
 - Reducing Load Per Processor
 - Minimize Number of Processors
 - Maintain Balance Between Internal and External Variables
 - Minimize I/O Between Levels


OPTIMAL PARALLEL COMPUTER ARCHITECTURE FOR INTERDISCIPLINARY MECHANICS SIMULATIONS


Densifying Solid- Fluid Model

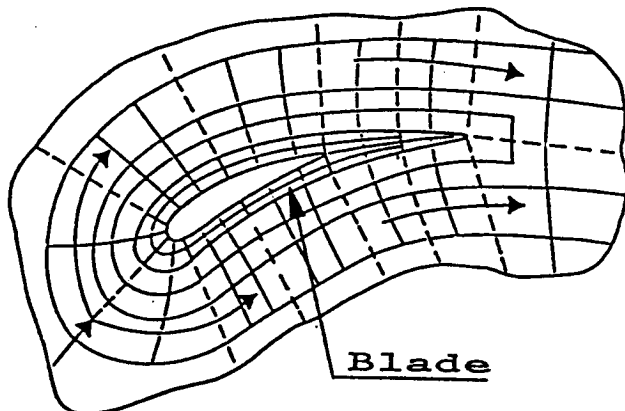


Level 1

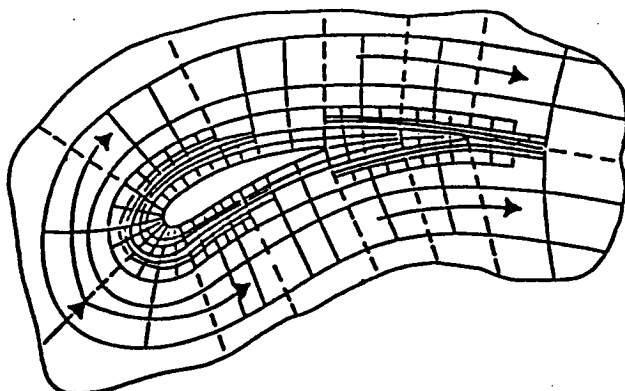
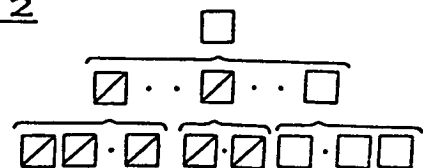


 -Fluid Processors

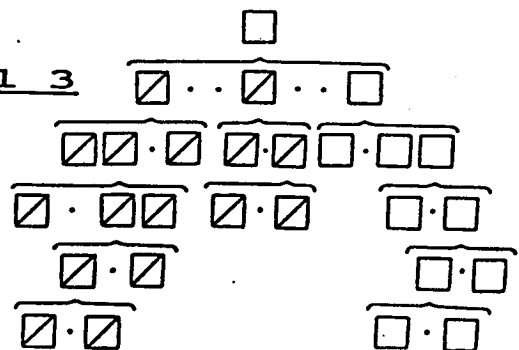
 -Solid Processors



Level 2



Level 3



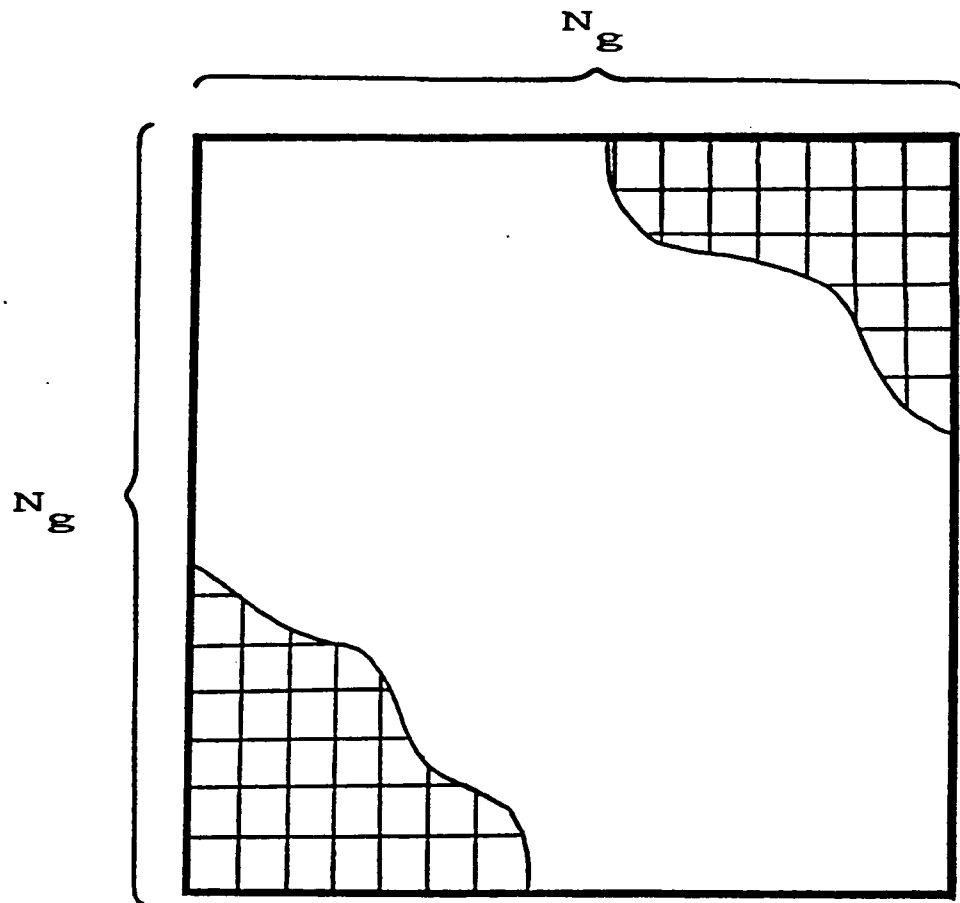
Example Problem

Given:

Consider Square Region With Fine
Uniform Mesh

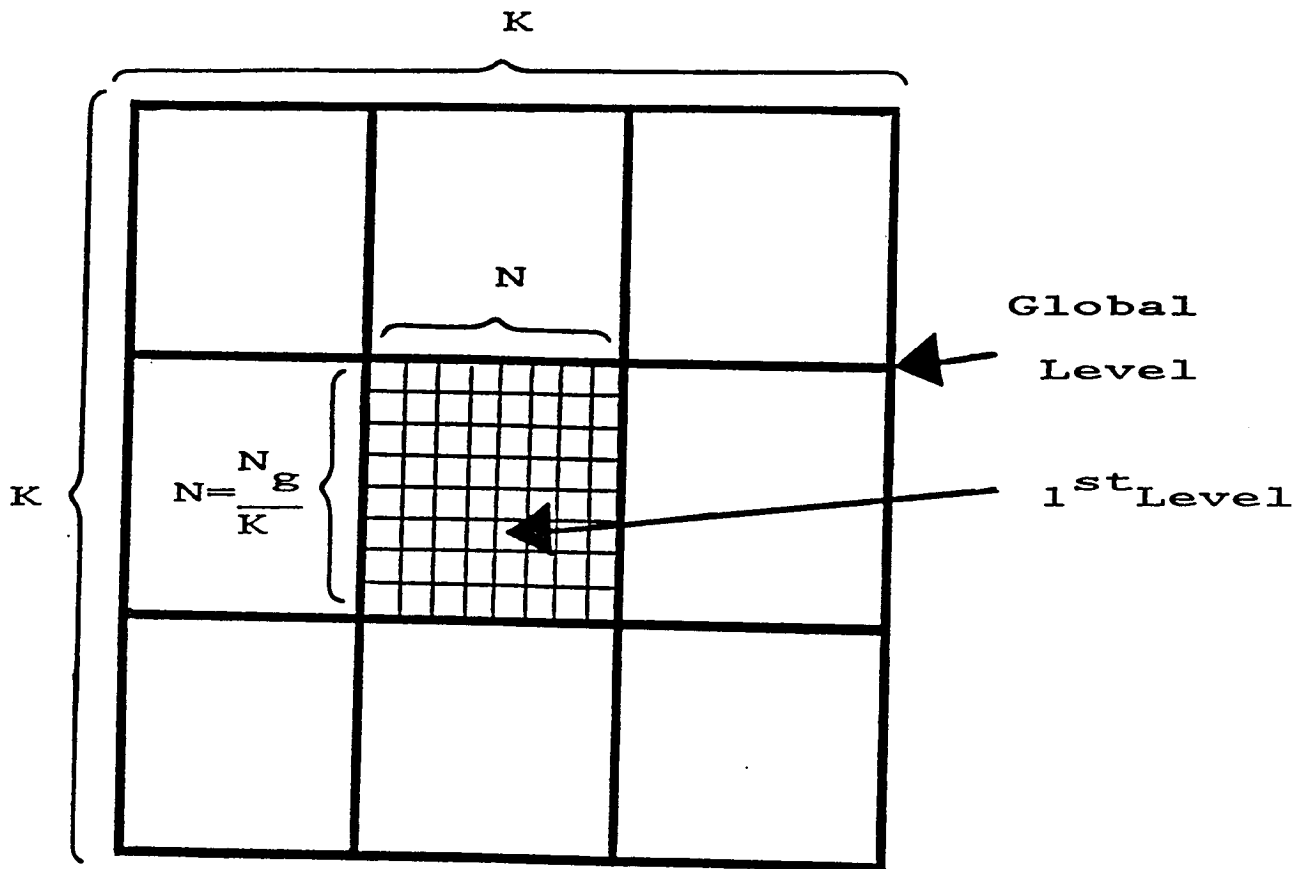
Problem:

Define Optimal Poly Tree

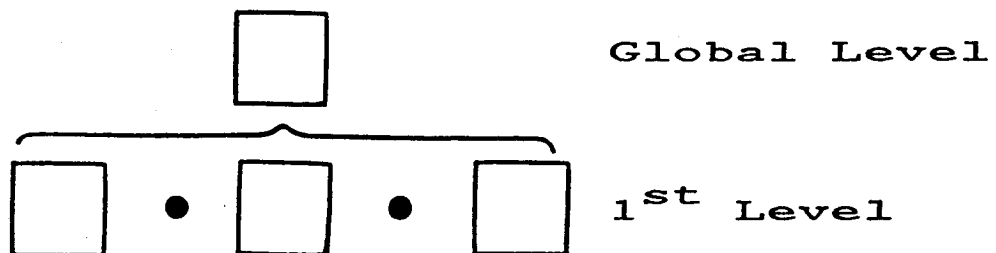


$(N_g)^2$ - Total Mesh Points

TWO LEVEL POLY TREE



POLY TREE



$K^2 + 1$ - Total Number of Processors

ASYMPTOTIC COMPUTATIONAL EFFORT:

TWO LEVEL

- STRAIGHT FULL SIMULATION

$$C_g \sim \frac{1}{4} (N_g)^4$$

- TWO LEVEL POLY TREE

$$C_0 \sim \frac{9}{4} K (N_g)^3$$

$$C_1 \sim \frac{9}{2} \left(\frac{N_g}{K}\right)^4$$

- COMMUNICATIONS

$$C_c \sim B_r (8(N_g)^2 + 8K N_g)$$

ASYMPTOTIC COMPUTATIONAL EFFORTS:

TWO LEVEL

• RATIO COMPARISON

$$R_P/g \sim \frac{\psi(C_0+C_1) + \frac{\Omega}{N_c} C_c}{C_g}$$

$$R_P/g \sim \psi \left\{ \frac{9}{(K)^4} + 4.5 \frac{K}{N_g} \right\} +$$

$$8 \frac{\Omega_B r}{N_c} \left\{ \frac{K}{(N_g)^3} + \frac{1}{(N_g)^2} \right\}$$

OPTIMAL SOLUTION

• GLOBALLY OPTIMIZED

$$\frac{d}{dk} (R_p/g) = 0 \rightarrow$$

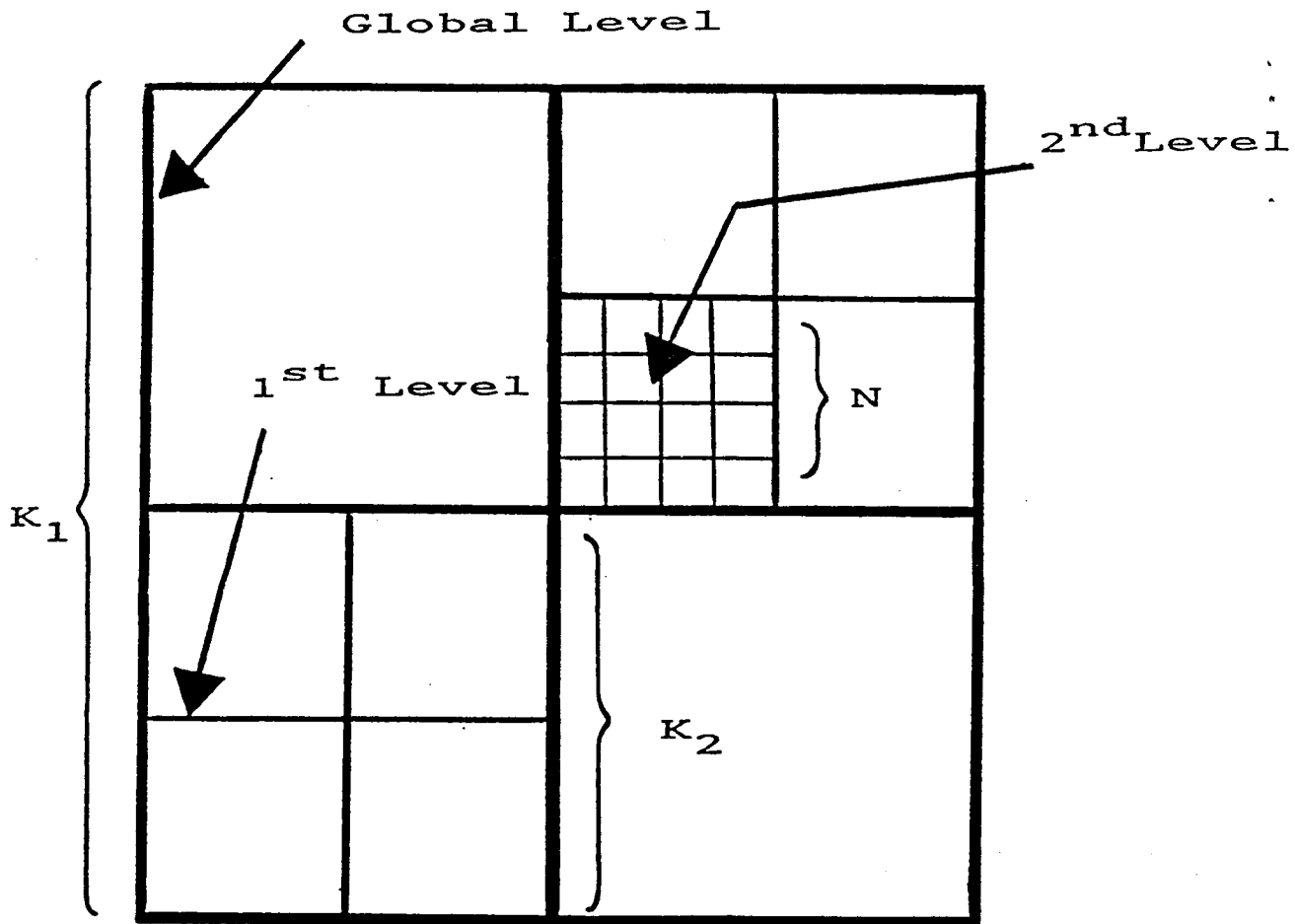
$$K \sim$$

$$\left[8 N_g \left\{ \frac{1}{1 + \frac{16}{9\psi N_c (N_g)^2} \Omega B_R} \right\} \right]^{1/5}$$

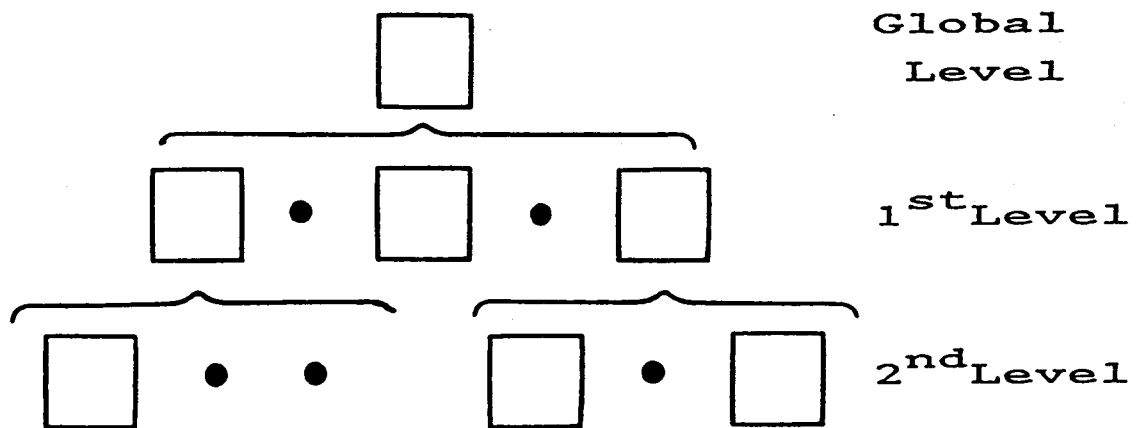
OPTIMAL TWO LEVEL POLY TREE

$(N_g)^2$	K	R_1/g	R_0/g	R_p/g	SPEED UP	NUMBER PROCESSORS
2.5×10^5	5	.045	.0144	.0594	17	24
2.5×10^7	8	.0072	.00219	.00939	106	64
2.5×10^9	13	.00117	.000315	.00148	673	169

THREE LEVEL POLY TREE



POLY TREE



ASYMPTOTIC COMPUTATIONAL EFFORT:

THREE LEVEL

$$C_0 = \frac{9}{4} K_1 (N_g)^3$$

$$C_1 \sim \frac{49}{4} \frac{K_2 (N_g)^3}{(K_1)^3}$$

$$C_2 \sim \frac{9}{4} \left(\frac{N_g}{K_1 K_2} \right)^4$$

$$R_{p/g} \sim$$

$$\underbrace{\frac{9}{(K_1 K_2)^4}}_{\text{2nd Level}} + \underbrace{\frac{49}{2} \frac{K_2}{(K_1)^3 N_g}}_{\text{1st Level}} + \underbrace{4.5 \frac{K_1}{N_g}}_{\text{0th Level}}$$

SUBOPTIMAL TRENDS: TWO LEVELS

$$R_{p/g} \sim \frac{9}{(K)^4} + 4.5 \frac{K}{N_g}$$

$$K \rightarrow \text{Large}; \quad K \sim O(N_g)$$

$$R_{p/g} \sim 4.5 \quad (450\%)$$

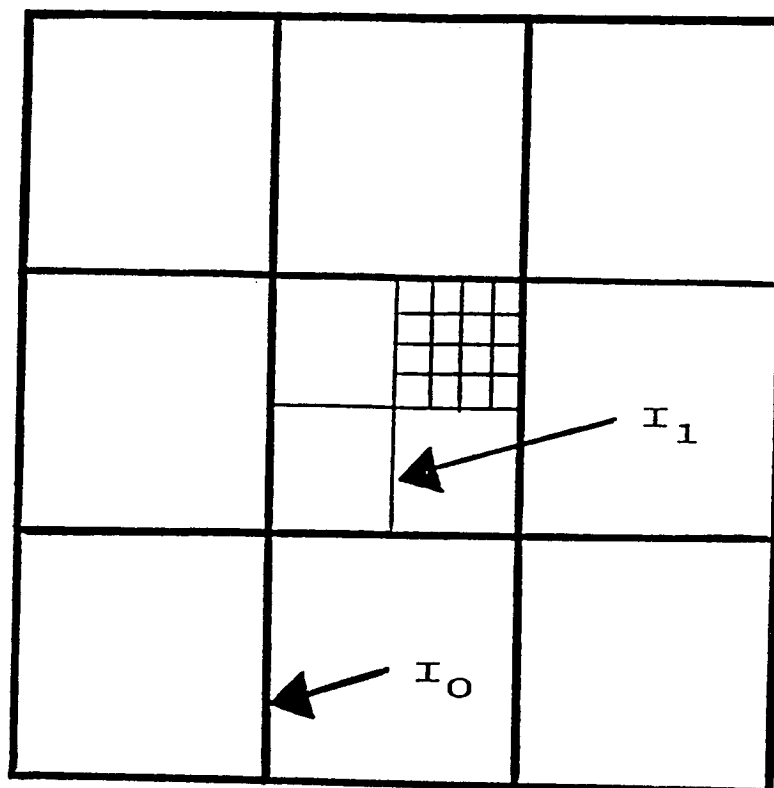
OPTIMAL THREE LEVEL POLY TREE; $N_g = 5000$

K_1/K_2	R_0/g	R_1/g	R_2/g	R_p/g	SPEED UP	NO. PROCESSORS
2/6	$.18 \times 10^{-2}$	$.37 \times 10^{-2}$	$.4 \times 10^{-3}$	$.58 \times 10^{-2}$	170	144
3/5	$.27 \times 10^{-2}$	$.91 \times 10^{-3}$	$.18 \times 10^{-3}$	$.38 \times 10^{-2}$	264	255
10/4	$.9 \times 10^{-2}$	$.19 \times 10^{-4}$	$.35 \times 10^{-5}$	$.9 \times 10^{-2}$	110	1600

OPTIMAL THREE LEVEL POLY TREE; $N_g = 50000$

K_1/K_2	R_0/g	R_1/g	R_2/g	R_p/g	SPEED UP	NO. PROCESSORS
2/8	$.18 \times 10^{-3}$	$.49 \times 10^{-3}$	$.13 \times 10^{-3}$	$.81 \times 10^{-3}$	1239	256
4/7	$.36 \times 10^{-3}$	$.54 \times 10^{-4}$	$.15 \times 10^{-4}$	$.43 \times 10^{-3}$	2335	784
10/6	$.9 \times 10^{-3}$	$.29 \times 10^{-6}$	$.7 \times 10^{-6}$	$.9 \times 10^{-3}$	1110	3600

INTERPOLATIVE REDUCTION : 3 LEVEL



<u>MESH LEVEL</u>	<u>REDUCTION</u>
Global	I_0
1 st	I_1
2 nd	1

INTERPOLATIVE REDUCTION: 3 LEVEL

$$C_0 \sim \frac{9}{4} K_1 (N_g)^3 (I_1 I_0)^3$$

$$C_1 \sim \frac{49}{4} \frac{K_2}{(K_1)^3 (N_g)} (I_1)^3$$

$$C_2 \sim \frac{9}{(K_1 K_2)^4}$$

$$R_{P/g} \sim$$

$$\underbrace{\frac{9}{(K_1 K_2)^4} + \frac{49}{2}}_{\text{2nd Level}} + \underbrace{\frac{K_2}{(K_1)^3 N_g} (I_1)^3}_{\text{1st Level}} + \underbrace{4.5 \frac{K_1}{N_g} (I_1 I_0)^3}_{\text{Oth Level}}$$

2nd
Level

1st
Level

Oth
Level

REDUCTION EFFECTS: THREE LEVEL POLY TREE;

$$\frac{N_g = 5000}{g}$$

$$I_1 = \frac{1}{2}, I_0 = \frac{1}{4}$$

K_1/K_2	R_0/g	R_1/g	R_2/g	SPEED UP		NUMBER PROCESSORS
				STRAIGHT	REDUCED	
3/5	5.3×10^{-6}	1.1×10^{-4}	$.18 \times 10^{-3}$	264	3386	225
10/4	1.7×10^{-5}	2.3×10^{-6}	$.35 \times 10^{-5}$	110	42920	1600

REDUCTION EFFECTS: THREE LEVEL POLY TREE;

$$N_g = 50000$$

$$I_1 = \frac{1}{2}, \quad I_0 = \frac{1}{4}$$

K_1/K_2	R_0/g	R_1/g	R_2/g	SPEED UP		NUMBER PROCESSORS
				STRAIGHT	REDUCED	
4/7	7×10^{-7}	6.7×10^{-6}	$.15 \times 10^{-4}$	2335	44,640	784
10/6	1.7×10^{-6}	3.6×10^{-8}	$.7 \times 10^{-6}$	1110	402,250	3600

Impact on Solvers

Static/Dynamic Poly Tree Architecture
Provides a Logical Framework for

- Direct Solvers
- Iterative Solvers
- Mixed (Direct/Iterative) Solvers
- Multi Time Scale Transient Solver
- Local/Global Constrained Nonlinear Solvers
- Mesh Refinement Procedures
- Interpolative Reduction (Saint Venants)
- Etc.

Summary

The Poly Tree Arrangement Yields

- Optimal Choice of Number of Processors Required for Given Problem
- Reduces Load Per Processor
- Reduces I/O Between Processors
- Enables Optimal Handling of Automatic Mesh Refinement
- Provide Most Natural Route for I/O Flow
- Enables an Orderly Way to Perform Interpolative Mesh Refinement

Future Directions

1. Continue Refinement of Scheme
2. Develop Associated Parallel Solution Procedure
 - Direct
 - Iterative
 - Mixed
 - Steady State
 - Transient
3. Establish requirements of Data Based Management System Required for Overall Control